ASD Technical Note 61-74

AEROSPACE VEHICLE PROTECTION
from
ATMOSPHERIC ELECTRICAL HAZARDS

Lightning & Transients Research Institute
Minneapolis, Minnesota
L & T Report 384
Contract No. AF 33(616)-7828

April, 1961

Jointly Sponsored by

Bureau of Naval Weapons
United States Navy
Washington, D. C.

and

Communications Laboratory
Aeronautical Systems Division
Air Force Systems Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

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Quarterly Report No. 1
Covering the Period
January 1961 through March 1961

Lightning & Transients Research Institute
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Project No. 1(670-4357)
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FOREWORD

This report was prepared by the Lightning & Transients Research Institute under Contract AF 33(616)-7828 sponsored jointly by the Aeronautical Systems Division, U.S. Air Force and the Navy Department, Bureau of Naval Weapons.

The technical program is administered under the direction of the Communications Laboratory, Aeronautical Systems Division, Mr. H. M. Bartman acting as project chief, and coordinated with the Bureau of Naval Weapons through Mr. V. V. Gunsolley.

Participating scientific and engineering staff taking primary part in this report's researches and preparation included: M. M. Newman, J. R. Stahmann, and J. D. Robb.

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ABSTRACT

Initial work on the contract was done on lightning protection of airships. High current artificial lightning discharge tests were carried out on four samples of lightning protection braid attachment systems supplied by NAS Lakehurst. The braid was intended for use in providing an external protection conductor network on the outside of the airship to prevent lightning discharges from entering the interior. Tests of the four samples disclosed that in each case excessive temperatures and burns occurred which could damage the airship envelope. On the basis of the results the sections were modified with locally available materials and additional tests were run. The tests on the additional sections in which thick insulation was provided between the braid and the envelope showed that the thicker insulation was effective in preventing excessive temperature rise in the envelope material; however, the more effective systems were also excessively rigid for airship use. An additional section incorporating the results of both series of tests with good thermal insulation to prevent excessive temperatures in the envelope material and suitable flexibility is proposed for a final test.

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LIST OF ILLUSTRATIONS

Airship Lightning Protection Braid Studies - II

I. Introduction

The initial period of the contract was spent on the specific problem of lightning protection for airships as requested by the Bureau of Naval Weapons. Tests were made to determine the optimum method of attaching external protection conductors on an airship to minimize the heat transferred to the airship envelope material, particularly at the point of direct lightning stroke contact. Consideration was also given to the magnetic and blast forces on the envelope and protection braid. Initial tests were made, on samples supplied by Lakehurst Naval Air Station, of four methods of attaching the braid to the airship envelope.

A strip of airship fabric with aluminum braid diverter strips was tested to determine its vulnerability to damage resulting from being hit by a lightning stroke. The aluminum protective braid, having a cross sectional area equivalent to a #6 solid wire and serving as the lightning current carrier, was passed through a fabric tunnel which held the braid in the center of the strip. As in Figure 1, the fabric test strip was divided into four sections, each with different tunnel or chafing strip materials.

The braid and its associated fabric components were tested using lightning current generators which duplicate components of natural lightning which would be most likely to damage the protection system.

The mechanical effect on the system caused by electromagnetic forces on conductors carrying lightning frequency magnitude currents was checked utilizing LTRI's high, medium duration, current generator. For the tests using this generator, the peak oscillatory currents were about 120 KA at 4 kcs. The waveform is shown in Figure 2. The heating effect of lightning was reproduced by a 200 coulomb generator having the waveform shown in Figure 3. The laboratory test setups were designed to simulate as severe conditions as possible, consistent with conceivable stroke approach paths, to determine the effects of stress in the airship fabric caused by mechanical forces and high heat concentration.

In addition to the stress on the fabric caused by the electromagnetic forces, there is the stress at the stroke contact point from the arc blast. The gas pressure force could initiate a tear in the airship fabric if the tunnel fabric is stronger than the airship fabric itself. Test section IV, where the braid tunnel fabric was the same as the airship fabric itself, approaches the undesirable tunnel fabric strength. However, no damage to the airship fabric was observed from the gas pressure blast on this section.

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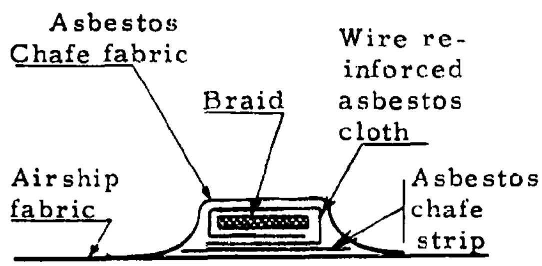
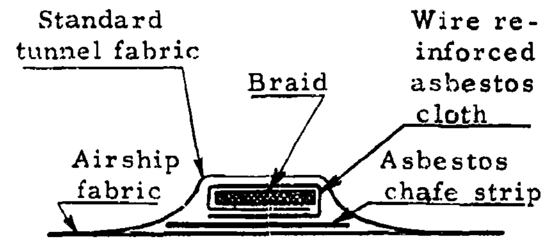
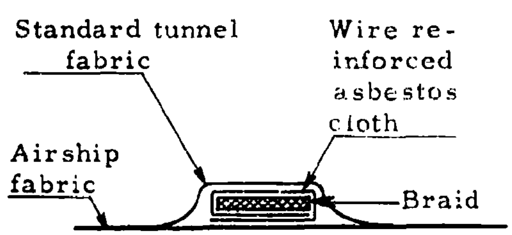


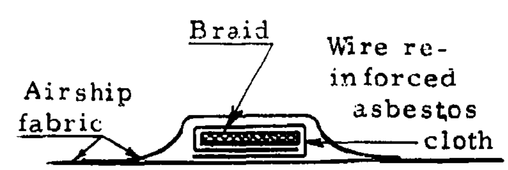
Test Section I



Test Section II



Test Section III



Test Section IV

Figure 1. Component parts of airship test strip.

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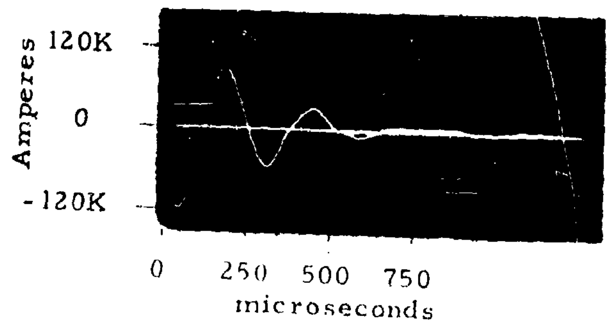

Figure 2. High current, medium duration generator waveform.

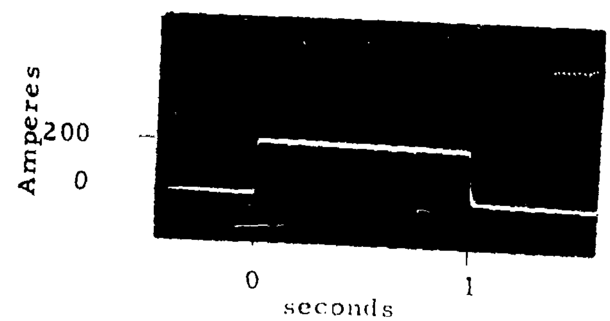

Figure 3. Two hundred coulomb discharge waveform.

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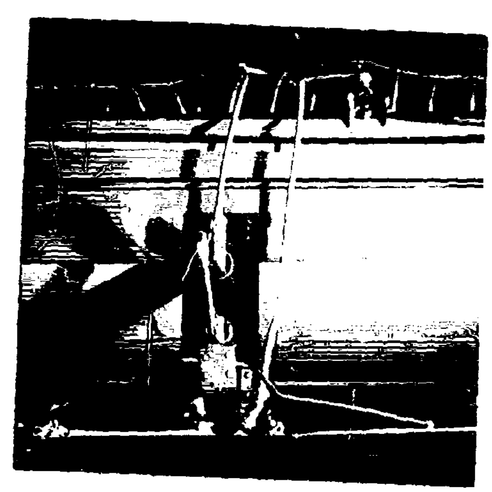

Figure 4. Typical airship fabric laboratory test setup.

An important consideration in the vulnerability of an airship from the effects of lightning stroke is one of heating. If the airship fabric is heated to a temperature of above 140°F. the material can be weakened. To duplicate the heat component of a natural lightning stroke, a long duration discharge of 200 amps for one second or 200 coulombs was passed through the braid.

The laboratory test setup, shown in Figure 4, was mechanically the same for the test strokes on all four sections. The test fabric was mounted in a horizontal position as the greatest portion of it would be on the airship. A longitudinal force of 400 pounds was applied to simulate the fabric tension. Tests were made in still air to simulate the "worst case" from a heating standpoint.

II. Test Results on Samples Supplied by NAS Lakehurst

Test section I consisted of the airship fabric, an asbestos chafing strip glued to the fabric, and the protective braid inside an asbestos fabric tunnel. The entire braid was covered with wire reinforced asbestos cloth with double thickness on the side next to the airship fabric.

The 120 KA high current test current pierced the braid tunnel cover and the asbestos wrap. The gas pressure due to the arc tore open the tunnel fabric and the asbestos wrap on the braid as shown in Figure 5 (a). The double thickness of asbestos wrap under the braid was not torn apart and the asbestos chafing strip was not scorched or damaged. The underside of the airship fabric showed no evidence of damage and it was not hot to the touch immediately after the stroke. Figure 5 (a) shows that the stroke vaporized the aluminum braid at the arc contact point. The gas pressure in the tunnel produced by the arc tore the tunnel fabric from the strip for about 14" in both directions from the arc contact point as shown in Figure 5 (b).

The 200 coulomb discharge to section I burned a 1/2" hole completely through the asbestos tunnel fabric, the asbestos wrap (both top and bottom), and the braid as shown in Figure 5 (c). The tunnel fabric or adhesive used caught fire around the arc point and burned for about 3 seconds after the discharge. The underside of the airship fabric was too hot to touch for more than an instant right after the discharge. The arc heat scorched the airship fabric under the hole in the braid, as shown in Figure 5 (d). A flash of fire also propagated along the edge of the asbestos tunnel where it is glued to the airship fabric. The flash extended for about 1 foot either side of the stroke point and was probably due to the burning of the adhesive material used.

Test section II consisted of the airship fabric, an asbestos chafing strip glued to the fabric, and an asbestos wrapped braid inside a tunnel of standard fabric.

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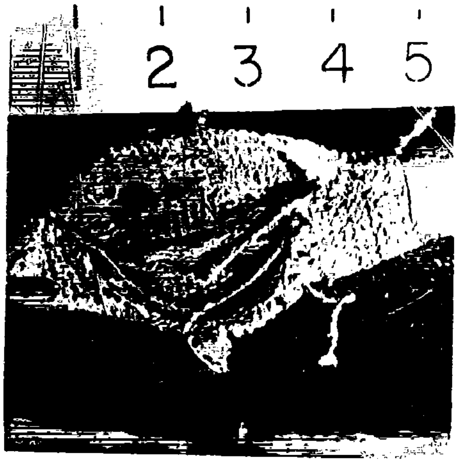
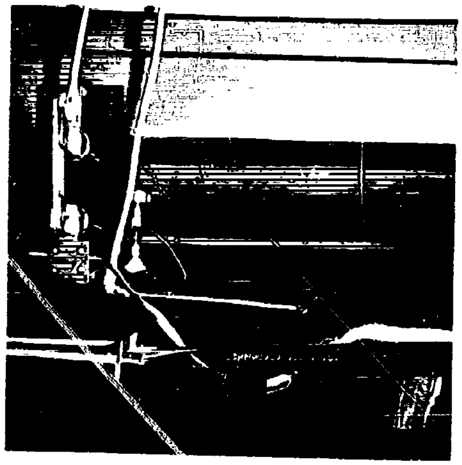
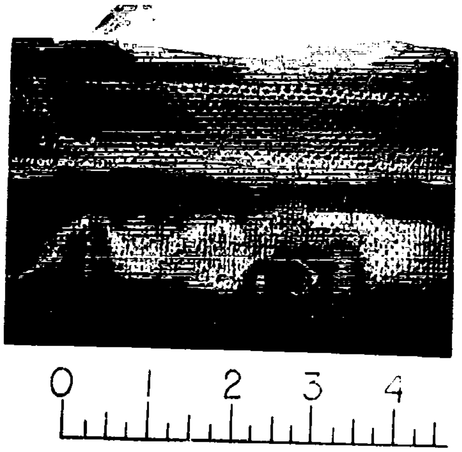


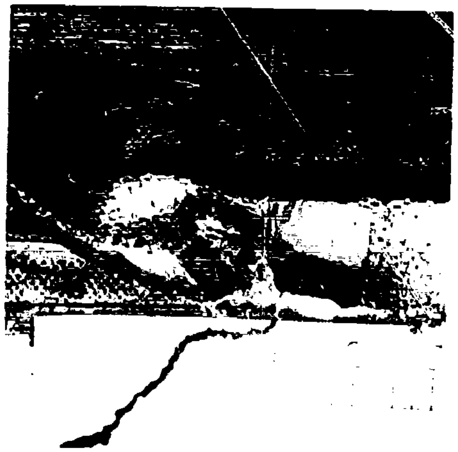
(a) High current damage at arc contact point.



(b) High current damage to tunnel.



(c) Tunnel fabric condition after 200 coulomb discharge.



(d) Braid hole and airship fabric scorch caused by 200 coulomb discharge.

Figure 5. Damage to airship test Section I from lightning currents.

The 120 KA peak current blew a 7" hole in the standard tunnel fabric and a 2" hole in the top side of the asbestos braid wrap shown in Figure 6 (a). As shown in Figure 6 (b), the double thickness underside of the asbestos braid wrap had a 1/2" slit in it. Approximately 70% of the braid strands were vaporized in the 3" section. The method used to construct the tunnel raised the braid about 1/4" off the airship fabric. This feature, coupled with the lighter tunnel material, resulted in less tunnel fabric damage than in section I.

The 200 coulomb discharge to section II resulted in little damage. As shown in Figure 6 (c), a 3/4" hole was burned in the light tunnel fabric and the top of the asbestos wrap. The standard tunnel material or adhesive burned for about 3 seconds after the discharge. The arc did not burn completely through the stranded braid as shown in Figure 6 (d). The airship fabric was only slightly warm because the braid was held off the chafing strip by tucking the tunnel under the braid so that it did not contact the chafing strip as in section I. The 1/4" air space between the braid and the airship fabric reduced the local heat intensity transmitted to the airship fabric at the arc contact point. This is in contrast to the heating of the airship fabric on section I where the braid and fabric are held tightly together.

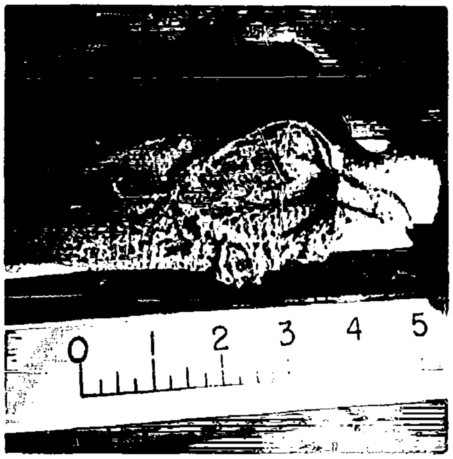
Test section III consisted of the airship fabric, the asbestos wrapped protective braid, and the standard tunnel fabric without the asbestos chafing strip.

The blast damage from the 120 KA peak current stroke was not severe. A 4" hole was torn in the standard fabric tunnel. In this test the asbestos braid wrap was not torn open. As shown in Figure 7 (a), the stroke current only separated the strands of the asbestos wrap. About 50% of the braid strands shown in Figure 7 (b) were vaporized. The airship fabric was only moderately warm after the stroke.

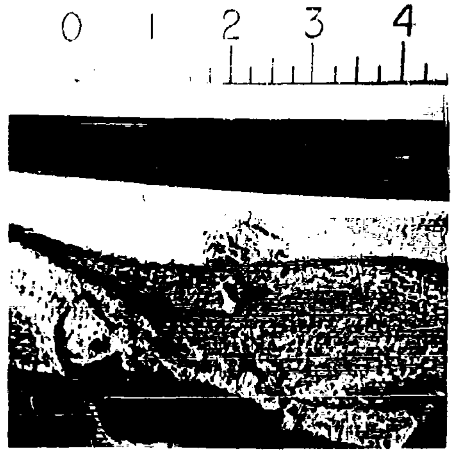
The damage to section III from the 200 coulomb discharge was similar to section II in that a hole was not burned through the underside of the asbestos braid wrap as illustrated in Figure 7 (c). However, unlike section II, a 1/2" hole was burned through the braid shown in Figure 7 (d). The standard tunnel fabric or adhesive burned at the arc point for 10 seconds after the discharge. This did not contribute to the heating of the airship fabric as the fabric was only slightly warm to the touch.

Test section IV consisted of the airship fabric, the asbestos wrapped protective braid, and an airship fabric tunnel with no asbestos chafing strip.

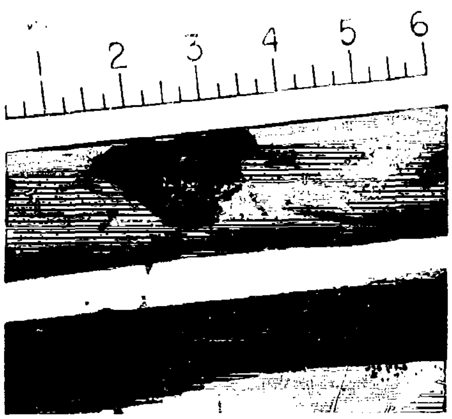
The gas pressure blast from the 120 KA peak current stroke blew off the tunnel fabric to a pair of clamps 7" either side of the arc point. The heavy tunnel fabric tends to try to confine the gas pressure because it does



(a) High current damage to standard tunnel fabric and asbestos braid wrap.



(b) High current damage to underside of double thick asbestos braid wrap.



(c) Tunnel fabric condition after 200 coulomb discharge.

(d) Braid condition after 200 coulomb discharge.

Figure 6. Damage to airship test section II from lightning currents.

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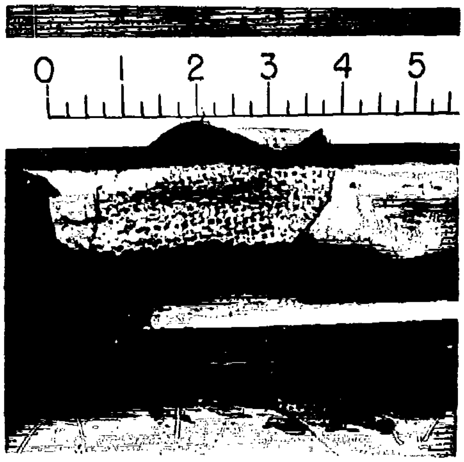
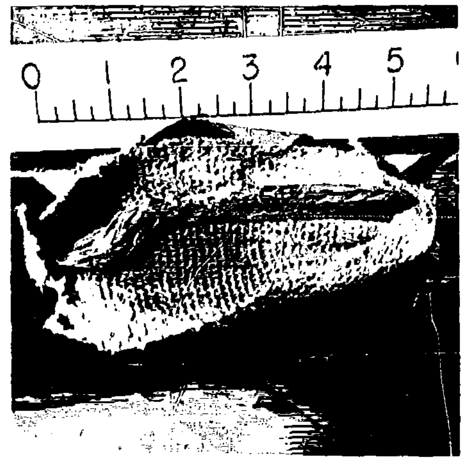
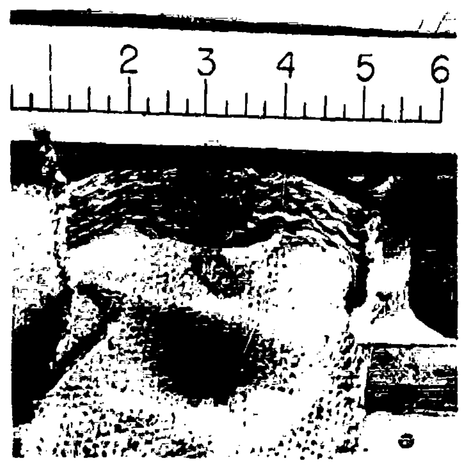


(a) High current damage to standard tunnel fabric and asbestos braid wrap.



(b) High current damage to braid.

(c) Tunnel fabric condition after 200 coulomb discharge.



(d) Braid condition after 200 coulomb discharge.

Figure 7. Damage to airship test section III from lightning currents.

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not tear easily to release the pressure as the light standard tunnel fabric does. The aluminum braid, shown in Figure 8 (a), was severed at the arc point probably because the heat confined in the tunnel aided in vaporizing the metal. Evidently the pressure inside the tunnel built up to the point where it released itself by breaking the glued seam between the tunnel and the airship fabric. Note that the tunnel was blown off of section I in the same manner where the heavier asbestos tunnel material was used.

The 200 coulomb discharge to section IV melted the braid strands at the arc contact point as shown in Figure 8 (b). The tunnel fabric hole of Figure 8 (c) is similar to that of the other three sections. A 1/2" hole burned through the double thick asbestos wrap under the braid and scorched the airship fabric as shown in Figure 8 (d). The underside of the airship fabric was too hot to touch immediately after the discharge and thus was weakened.

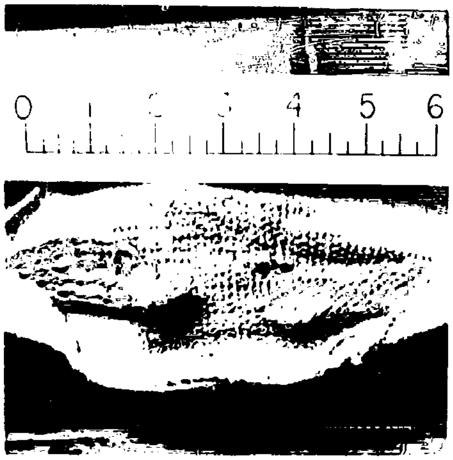
The high current strokes did not cause the braid to pull out of the connector lugs at the braid ends as in tests reported earlier in LTRI Report No. 366. The double thickness of the braid in the lug hole along with compression stress reduces the possibility of the braid strands pinching and pulling out during a stroke. As shown in Figure 9, the braid did not pull out from the lug but some strands of braid were broken in an area 3" back from the lug. In Figure 9 the braid is shown expanded to reveal the section with broken strands.

The results may be summarized as follows:

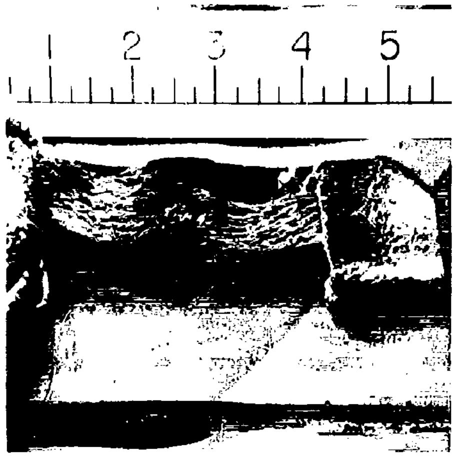
The aluminum braid and its associated fabric components protected the airship fabric against the damaging effects of the two lightning current components used in the study. Sections II and III were damaged the least of the four sections tested. These two sections utilize the standard tunnel fabric which allows arc gas pressure and heat to escape because it is lightweight and easily torn. The protection components and configuration of these two sections are identical except for the additional chafing strip in Section II. The high current strokes to sections II and III did not completely vaporize the braid cross-section while in sections I and IV the cross-section was vaporized. Compared to sections I and IV, where the airship fabric underside was too hot to touch after a 200 coulomb discharge, sections II and III were only warm.

The heavy tunnel fabric of sections I and IV act to contain the heat whereas the lighter standard tunnel fabric allows it to escape.

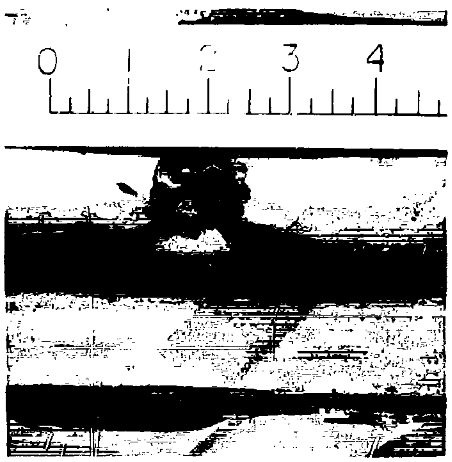
In sections II and III the braid is held above the airship fabric by approximately 1/4" as shown in Figure 10. This retards heat conduction from the braid to the airship fabric. This is compared to the braid being held tight against the airship fabric in sections I and IV. The chafing strip on sections I and II aids in protecting the airship fabric from arc heat and from mechanical punctures.



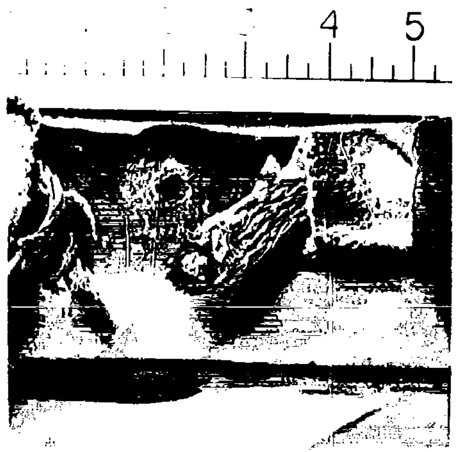
(a) Braid condition after high current stroke.



(b) Braid condition after 200 coulomb discharge.



(c) Tunnel fabric condition after 200 coulomb discharge.



(d) Airship fabric scorch caused by 200 coulomb discharge.

Figure 8. Damage to airship test section IV from lightning currents.

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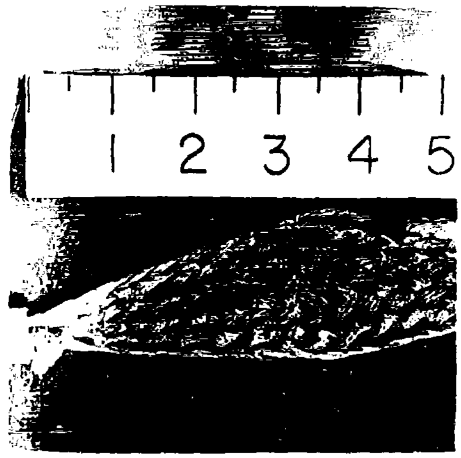


Figure 9. Strand breakage in braid from lightning currents.

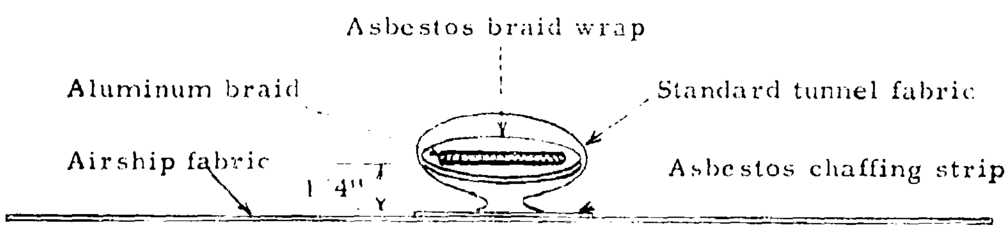


Figure 10. Cross section of test strip showing 1/4" spacing.

III. Additional Tests on Modified Samples

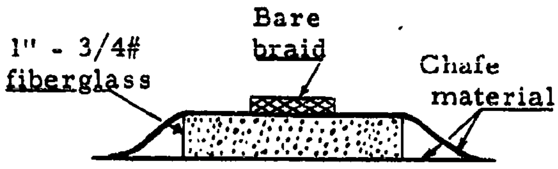
Since the sections tested were not satisfactory from a heating and fire hazard point of view, we tested various configurations of the available materials as shown in the test drawings of Figures 11 through 15 attached. A thermocouple was used to measure the temperature of the underside of the fabric. From these results it appears that, for example, using the materials and basic design of Lakehurst section I, a satisfactory system may be made by using a three layer asbestos wrap and about two layers for the asbestos chafing strip. The chafing strip should be widened to about 2 feet to protect against spraying molten metal. Increasing the wrap thickness helps confine the arcs and reduces metal spray, while increasing the chafing strip thickness helps reinforce the envelope as well as providing heat insulation. If such a system is not too heavy, a sample strip should be made up and tested. A lighter tunnel cover fabric would be preferable. If a lighter tunnel fabric is used with an air space, as in Figure 10 of the report, only one chafing layer probably would be necessary.

Satisfactory test configurations using fiberglass alone required a one inch thickness of 3# fiberglass (see Figure 13, upper right hand corner) or 16 layers of fiberglass cloth (see Figure 11, upper right hand corner). While fiberglass might be obtained with a special weave having sufficient stretch to follow the airship envelope expansion and contraction, there does not appear to be much difference between the fiberglass and asbestos insulation for our purposes. The specific heat of asbestos is slightly higher than glass. The asbestos burns away but similarly the fiberglass melts away to about the same degree. The best available Minnesota Mining fire retardant adhesive was obtained and tested. Minnesota Mining EC-1324 adhesive burned briefly when used as a cement on or near the braid. During tests the Lakehurst test strip also showed flashes of fire which propagated along the strip, probably due to burning adhesive residue. These flashes immediately extinguished. An adhesive which will not burn briefly under our test conditions has not been located. Until such an adhesive can be located, a minimum of adhesive should be used with any residue located as far away from the braid as possible.

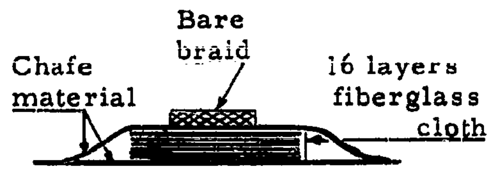
IV. Concluding Discussion

Fundamentally three important factors to be considered in attaching the braid to the fabric are:

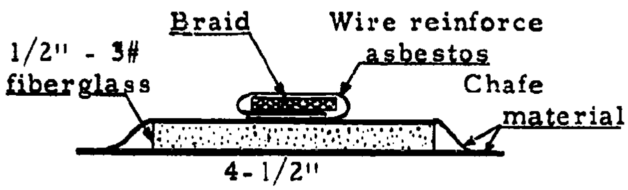
(a) The covering tunnel fabric must be of lighter material than the envelope fabric since any gas or arc pressure built up in the tunnel should be released by destruction of the outer covering without damage to the envelope fabric.



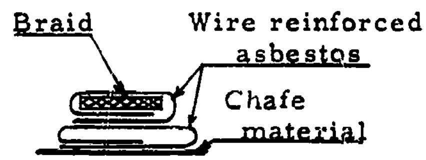
300A - 14 seconds 420 = Q
No temperature rise
90% of strands melted
Chafe material burned crisp
(under braid)



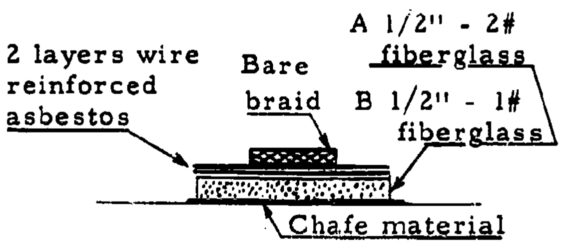
320A - 1 second 320 = Q
No temperature rise
60% of braid strands melted
Top chafe material scorched



280A - 14 seconds 392 = A
No temperature rise
50% of braid strands melted
1" hole burned in braid and wire
reinforced asbestos

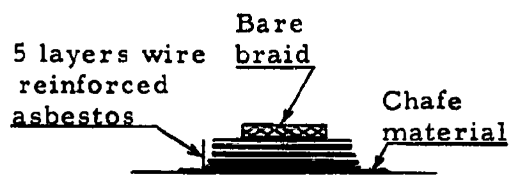


100A - 2.6 seconds 260 = Q
No temperature rise



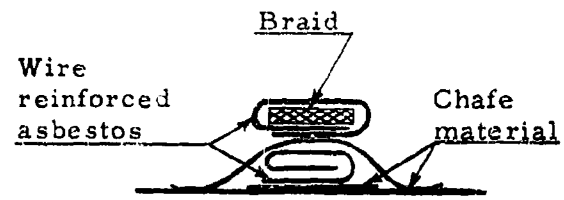
A 100A - 2 seconds 200 = Q
No temperature rise

B 100A - 2 seconds 200 = Q
No temperature rise



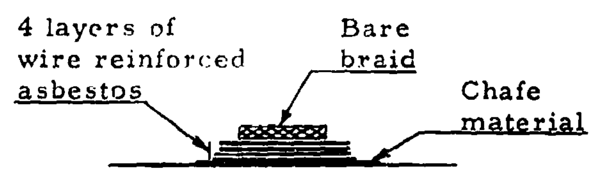
100A - 2 seconds 200 = Q
No temperature rise

Figure 11. Experimental lightning protection braid sectors with no temperature rise.



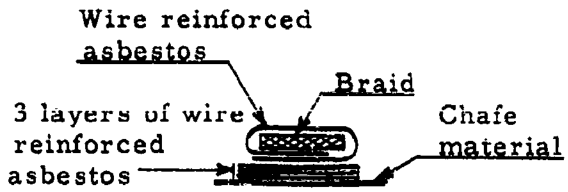
180A - 2 seconds $360 = Q$
Temperature rise to $90^\circ F$
1" dia hole burned in braid and
2 thicknesses of WRA

170A - 2 seconds $340 = Q$
Temperature rise to $95^\circ F$
1" dia hole burned in braid and
1 thickness of WRA



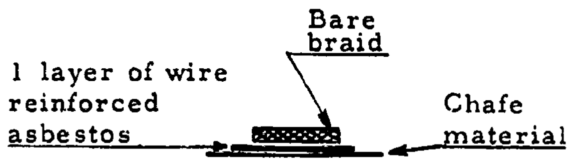
100A - 2 seconds $200 = Q$
Temperature rise to $95^\circ F$
No hole burned in WRA

Figure 12. Experimental lightning protection braid sectors with temperature rise to less than $100^\circ F$.



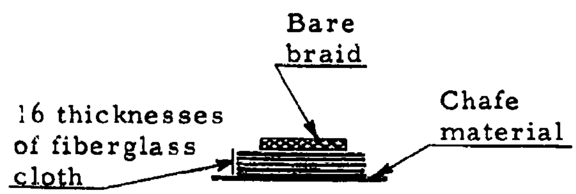
340A - 1.4 seconds 476 = Q
Temperature rise to 105°F
Top layer - the WRA burned through

240A - 1.4 seconds 336 = Q
Temperature rise to 125°F
1/2" deep hole burned in fiberglass
80% of braid strands melted



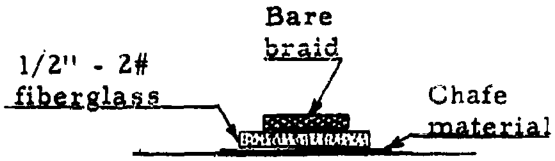
100A - 2 seconds 200 = Q
Temperature rise to 115°F
A 1/4" dia ball of molten aluminum layed on the WRA after arc

120A - 2 seconds 240 = Q
Temperature rise to 118°F

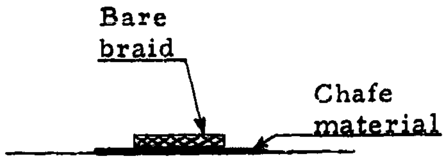


320A - 1.4 seconds 448 = Q
Temperature rise to 130°F
14 thicknesses burned through

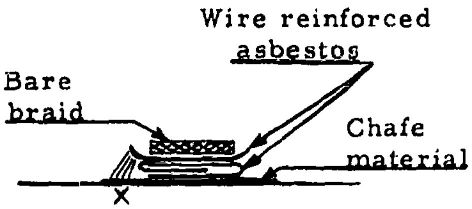
Figure 13. Experimental lightning protection braid sectors with temperature rise of between 100° and 135°F.



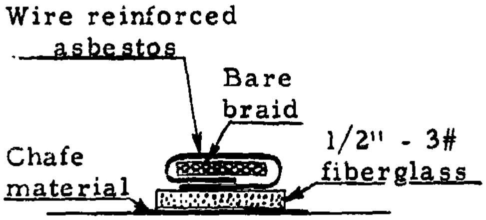
150A - 2 seconds 300 = Q
Temperature rise to 225°F
Arc burned hole through fiberglass



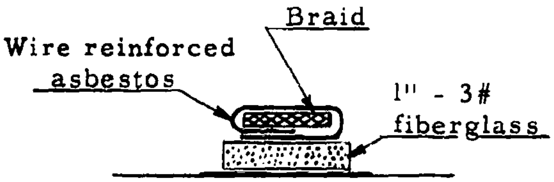
160A - 1.2 seconds 192 = Q
Temperature rise to 135°F



180A - 2 seconds 360 = Q
Temperature rise to 165°F at X
point on airship fabric. Hole
burned through top thickness of
WRA and arc contacted fabric as
shown.

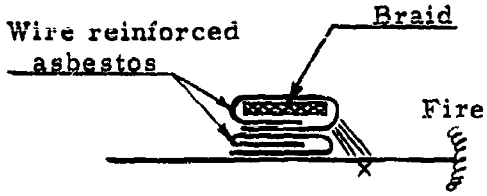


250A - 1 second 350 = Q
Temperature rise to 210°F where
hole burned through fiberglass
70% of braid strands melted
1" dia hole burned in wire reinforced
asbestos.

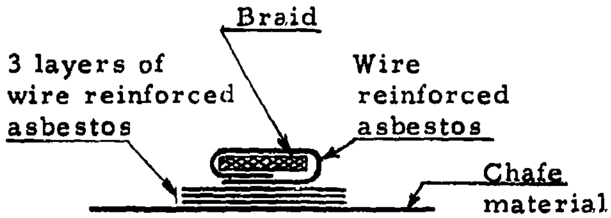


300A - 1.4 seconds 420 = Q
Temperature rise to 215°F where
hole was burned through fiberglass
60% of braid strands melted
1-1/2" dia hole burned in wire
reinforced asbestos

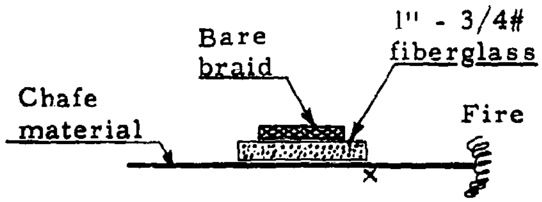
Figure 14. Experimental lightning protection braid sectors - temperature rise to over 135°F.



180A - 2.2 seconds 396 = Q
Airship fabric was burned crisp at the X mark. A fire started at the edge of the airship fabric.



340A - 1.4 seconds 476 = Q
No temperature rise under arc point.
A fire started at edge of airship fabric.



300A - 1.4 seconds 420 = Q
2" hole burned in fiberglass
Airship fabric burned crisp at X mark. Fire started at edge of airship fabric.
75% of braid strands melted

Figure 15. Experimental lightning protection braid sectors. Fires started.

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(b) There must be sufficient heat insulation between the braid and envelope fabric to prevent a temperature rise of the envelope which would weaken it. We understand that the maximum temperature that the fabric will withstand without damage is of the order of 140° F.

(c) The material which can be contacted by the molten braid must not support combustion. Our tests showed that the envelope fabric could support combustion.

The results may be briefly summarized as follows:

(1) There was no evidence of fabric tears or other mechanical damage to the envelope fabric due to high current discharges.

(2) The improved lug connectors were satisfactory although some broken strands were noted in the braid itself near the connector.

(3) Initially section II appeared the best of the four Lakehurst test sections because the tunnel cover fabric blew open easily and an air space (see Figure 10 of report) between the asbestos wrap and envelope fabric provided heat insulation protection. However, all sections caught fire and burned for a short period in still air after application of the long duration current component and, since the standard fabric tunnel used in section II can support combustion, it is not considered acceptable. While the air space in section II provided heat insulation during our tests, it may be difficult to prevent the braid from sagging to the envelope on the airship.

(4) Section I was not satisfactory as tested because of insufficient heat insulation between the envelope fabric and the braid and because of the somewhat heavy asbestos cover fabric which may cause pressure build up. However, the material used does not support combustion. Thus this section may possibly be improved so that it is satisfactory.

In view of the results of the data, an improved "Section I" as outlined above appears optimum and should be made up and tested during the next report period. Other work planned for the coming period includes the development of test methods and standards for lightning diverters and precipitation-static dischargers. Also planned is the theoretical investigation of the effects of ionization on the atmosphere on lightning discharge paths in relation to their possible action in guiding lightning strokes on radar beams and jet engine exhaust trails.